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AUTHOR Dillon, Ronna F.
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ABSTRACT

Current pscyhometric assessments, which are based on test score predictors providing information only on products of performance, fail to account for satisfactory amounts of variance in academic achievement or other criterion measures of interest. To corroborate and extend previous work on information processing measures, by examining the differential predictive power of a process based on eye movement data compared to test score information, two studies were conducted. The eye movements of 39 college students (19 in the first study; 20 in the second study) were recorded during the solution of a set of 3 x 3 figural analogies from the Advanced Progressive Matrices (APM). A stimulus was presented on 35 millimeter slides with eight possible responses. The subject's head was positioned against chin and forehead rests. A calibration procedure preceded eye movement data collection. An analysis of the results from both studies showed that the process model based on eye movement data yielded greater prediction of academic achievement than did models based on test score data. Indices reflecting the amount of information that can be processed at a given time, and the allocation of processing resources to activities involving rule application accounted for significant amounts of variation in grade point average (GPA). Specifically, individuals earning relatively high GPAs were characterized as processing information in relatively large units with little redundancy, and expending a small percentage of their total processing resources on rule application activities. (BL)

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Eye Movement Models of Academic Achievement

Ronna F. Dillon

Southern Illinois University at Carbondale

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Running Head: Eye Movement Models of Achievement

Abstract

The work reported herein is designed to test the premise that, because common elementary operations underlie performance on both IQ test-type tasks and general academic criteria such as grade point average, such process measures are potent predictors of academic success. The predictive superiority of process models, over test-score data, is believed to result because test scores measure only the products of performance and thus are most closely tied to particular knowledge stores and procedural rules specific to given test items. Two studies are reported in which eye movements are recorded during solution of a set of 3 x 3 figural analogies. Backward stepwise regression analyses indicate that models based on eye movement data account for significant amounts of variation in academic achievement, with these process models outstripping models based on test-score data. Implications for diagnosis and prescription are considered.

Predicting Academic Achievement with Models Based on Eye Movement Data

The need to improve prediction of important external criteria in academic and technical or professional settings is an issue of widespread concern among psychologists and educators (cf. Sternberg 1981). Interested investigators contend that typical psychometric assessments rarely account for satisfactory amounts of variance in academic achievement or other criterion measures of interest. Moreover, such assessments are based on test-score predictors which provide information only on the products of performance and, thus, are diagnostically and prescriptively barren.

A growing number of investigators are calling for the development of techniques that supplement current testing approaches by information-processing procedures. The present work was undertaken to address this need through the use of process models based on eye movement data. Such process information is designed not only to enhance criterion-related validity, but to provide information regarding the information-processing components and strategies underlying variation on tasks requiring nontrivial mechanisms as well. Like other cognitive components work (see Sternberg 1981 for a discusion of potential contributions of cognitive components research to testing practices), our work is designed to isolate specific loci of obtained correlations with respect to harnessable mechanisms. Such information may form the basis of subsequent prescriptive efforts.

Measures of ongoing processing should provide more powerful frameworks for predicting variation in performance on external measures of cognitive

functioning because these indices tap the range of mechanisms individuals bring to bear during reasoning and problem solving, in addition to discipline-specific knowledge stores and procedural rules and skills. Such process models should be particularly potent because predictors directly tap common individual differences in cognitive processes underlying performance on both predictor and criterion tasks; processes that cut across content domains. Thus, a more robust predictive system is expected to result from the use of process models.

In cognitive components work, latencies of component execution can be derived (see Pellegrino & Goldman 1983; Sternberg 1981). In previous work, processing differences underlying differences in component latencies remained largely unspecified. Our work utilizing models based on eye movement data appears promising in this regard. Individual differences in (a) absolute expenditure of processing resources and relative resource allocation to the various processing stages can be elucidated, as can (b) individual differences in the sequential ordering of processing steps, (c) the use of strategy components, and in (d) gross differences in program systems used by different subjects.

Snow (1979) points to the fruitfulness of studying the levels of process differences mentioned above. Study 1 reported herein uses differences in the sequential ordering of processing steps as predictors while Study 2 also considers predictors based on resource allocation in the different processing stages.

Previous eye movement research (Dillon & Wisher, 1981) linked eye move-

ment data, recorded during solution of complex analogical reasoning items, to variation in arithmetic reasoning, spatial perception, and word knowledge among Navy recruits. Specifically, increments in Navy task performance were related to hypothesis-generate scanning demonstrated by factors such as a relatively late initial break in ongoing item processing, fewer breaks in main array processing, and higher ratios of larger unit row and column scans to total scans with increasing Navy-task score. The two studies reported herein are designed to provide corroboration and extension of previous work, by examining the differential predictive power of process models based on eye movement data versus product (i.e., test-score) information for college students.

Study 1

Study 1 was designed to compare the predictive validity of eye scan indices to test score information, for predicting general academic achievement, using models based on differences in scanning efficiency across problem-solving stages. These indices have been found to predict Navy task performance among recruits (Dillon & Wisher, 1981).

Method

Subjects. Nineteen college undergraduates served as subjects. Males and females were approximately equally represented. All subjects had normal uncorrected vision.

Materials. Fifteen items were selected from the Advanced Progressive Matrices (APM: Raven, 1962). Each item depicted a 3 x 3 figural analogy in the main stimulus array. A set of eight possible responses (i.e., distrac-

tors) was located beneath the main array in each item, only one of which correctly completed the particular analogy. Items were recorded separately on 35mm slides for presentation. Item difficulty was varied randomly across the 15-item set. Cumulative grade point average was recorded for each subject.

Procedure. Each slide was presented to the subject on a rear-screen projector. The Whittaker 1992 was used to track eye fixations. The subject's head was positioned against chin and forehead rests. An eye-level screen was viewed from a distance of 57cm. The pupil-centered corneal reflectance system computed the subject's point-of-regard from horizontal and vertical reference points at 60Hz. Subtended visual angle was 12 degrees in both vertical and horizontal directions. Eye fixations were defined by the absence of change in eye position exceeding 1 deg. for a period of $\geq$ 125msec. The intersection of the horizontal and vertical crosshairs superimposed on the video output of each Raven item defined the fixation point. A videotape record of each trial was collected during problem solution, and eye position data were input to an IBM-370 for data reduction and analysis.

All testing was done on an individual basis. Each subject underwent a brief calibration procedure prior to eye movement data collection. Immediately prior to the onset of each trial, subjects were instructed to fixate a point at the center of the screen on which the slides were displayed. At the experimenter's signal, the subject began item solution. When the subject reported the number corresponding to the chosen response alternative, the trial was terminated Calibration was checked following each trial and adjusted as necessary.

The set of analyses performed in both studies was aimed at investigating

the predictive validity of the scanning indices defined in Table 1. The reader

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Insert Table 1 about here

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is referred to other sources (Dillon & Stevenson-Hicks, Note 1, Note 2) for a more detailed treatment of the scanning indices and the manner in which underlying processing is affected by various task manipulations and subject characteristics.

Results and Discussion

Analyses were conducted to determine the criterion-related validity of eye scan indices vis-à-vis test score data, both taken from solution of the APM items. A number of scanning indices have been found in our work to relate to reference ability measures (Dillon & Stevenson-Hicks, Note 1) and to predict total score variation on the APM (Dillon & Stevenson-Hicks, Note 2). In the present study, a two-variable model accounts for 42% of the variance in cumulative grade point average (GPA), $F(2,18) = 5.84$, $p<.05$. Using a backward stepwise elimination procedure (SAS; Helwig & Council, 1979), the two significant predictors (both negatively weighted) are (a) total number of fixations over all trials, and (b) the percentage of total analyzable units that are binary column scans, where an analyzable unit is any of the following scans: (1) total row; (2) total column scan; (3) binary row scan, defined as three fixations between two points in a row; and (4) binary column scan. With respect to the criterion-related validity of APM score (as opposed to eye movement data), analysis indicates that 30% of the variance in GPA is accounted for by a model

based on test-score information, $F(1,18) = 7.17$, $p<.05$.

Thus, increments in academic achievement are related to eye scan indices reflecting the number of fixations and the percentage of scans of various lengths, to a greater degree than to changes in APM score. Increments in speed or brevity of information processing, and large-unit processing reflecting the ability to process relatively greater amounts of information are aptitude dimensions of common importance in reasoning task performance and overall academic achievement. A lesser degree of commonality exists between (a) the knowledge and content-related demands of the Raven analogy (tapped by APM test score) and (b) general academic performance.

Study 2

Study 2 had two purposes. First, the study was conducted to provide corroborative evidence of the differential predictive power of process models based on eye scan data versus product (i.e., test-score) information. Second, the study was undertaken to ascertain additional increments in predictive power possible when eye scan models are comprised of predictors tapping two levels of individual differences: i.e., the sequence indices used in Study 1, and predictors tapping energy expenditure in each problem-solving stage.

Method

Subjects. Twenty college undergraduates served as subjects. Subjects had normal uncorrected vision or normal vision corrected with hard contact lenses. Males and females were approximately equally represented.

Materials and Procedure. The materials and procedure were identical to those used in Study 1.

Results and Discussion

The predictive potency of models based on eye movement data was compared to the proportion of variance in GPA that could be accounted for by changes in APM score. Analysis indicates that the most potent sequence scanning indices pertain to row and column scan lengths; i.e., the percentage of total analyzable units that are binary column scans, and that are total row scans, with the 2-variable model accounting for 50% of the variance in GPA, $F(2,19) = 8.93$, $p<.01$.

When an index reflecting energy expenditure in a specific problem-solving stage was added to the sequence indices, the variance in GPA accounted for by eye scan data increased to 64%, $F(3,19) = 9.88$, $p<.001$. The significant stage predictor pertained to energy expenditure in rule application processes (i.e., application of transformational rules inferred in a prior stage of item solution). The weight reflects (as does the negative weight for the binary column index) that increments in GPA are related to decrements in the eye scan index; in this case, decreases in amount of rule application processing. Score on the APM accounts for 7% of the variance in GPA.

Taken together with the results of Study 1, the picture that emerges is one in which variation in overall academic achievement is related to increments in the ability to process large amounts of information at a given time, and decrements in the percentage of processing activity devoted to rule application processes. The work corroborates other cognitive components findings (see Sternberg, 1979), where successful problem solving is seen to be related to a decrease in processing energy devoted to application and conformation processes,

with increases in encoding and rule inference activities.

General Discussion

The results of the studies reported herein indicate that process models based on eye movement data yield greater prediction of academic achievement than do models based on test-score data. Indices reflecting the amount of information that can be processed at a given time and the allocation of processing resources to activities involving rule application account for significant amounts of variation in GPA. Specifically, individuals earning relatively high GPA's can be characterized as processing information in relatively large units with little redundancy, and expending a small percentage of their total processing resources on rule application activities.

Eye scan models outstrip test score information because the latter (i.e., product) assessment cannot take the subject's processing approach into account; it simply measures the end product. Such product information is more likely to reflect knowledge stores, and learned rules and procedural skills specific to the particular discipline under investigation. Process models, in contrast, also reflect general information-processing parameters and the combination of processes into strategies. These elements of ongoing processing are believed to possess greater generality than data tapped through test scores. The former processing phenomena are thought to be manifested across a wide range of tasks requiring intelligent behavior, and are thought to tap common processes manifested on college exams (yielding a cumulative GPA) and inductive reasoning tasks such as the APM.

In addition to other goals stated previously, our research activities are

designed to achieve greater external validity than has been the case with previous endeavors. This aim necessarily increases the complexity of our central goal; i.e., to understand the role of fundamental cognitive operations and the strategies into which these operations combine, in performance on complex IQ test-type tasks.

Because our interest is in understanding the operation of elementary processes in complex cognitive problems, our tasks have been the kinds of problems we ultimately are interested in understanding, rather than looking at simple task performance and correlating performance measures with the more complex IQ test-type tasks. Further, unlike other componential endeavors, our measurement techniques permit examination of intact items as opposed to subtasks or partial tasks. Inferences about complex processes from such items may be more straightforward. The obvious price of this approach is a greatly increased processing complexity which must be explained.

The second issue concerns the use of data from the entire data set as opposed to restricting analyses to correct responses. If one were trying to account for performance on a particular task by comparing models of various process predictors, limiting data to correct responeses should simplify matters. However, data from incorrect as well as correct responses may be more appropriate. For example, earning a given grade point average is the result of a host of rule induction behaviors as well as other less systematic processes. Thus, if one's criterion were general, such as GPA, examination of scanning patterns from the entire data set might capture this richness more veridically (and thereby avoid inflated estimates) than by simply looking at correct trials.

The generality of scanning indices used should reflect the level of inclusiveness of the criterion, as well. Again, the researcher's task becomes more difficult.

A related issue concerns data analysis. Attempts to understand task properties may involve consideration of an entire ability range as a single group. Clearly, our interest typically is in describing indiviuals who occupy an entire ability continuum. Note that considering only correct trials is equivalent to looking just at "high skill" subjects.

Finally, one needs to note additional difficulties that arise when one strives to characterize individual differences in a population such as college students, wherein restriction of range is obvious. Attempts to select disparate skill groups are common, and result in some modest range. Again, such is the nature of the phenomena of interest when one desires to understand individual differences in information-processing abilities among college students.

In addition to yielding increased prediction of a general academic criterion, the use of eye movement predictors appears to hold considerable promise of being diagnostically and prescriptively fertile. Score deficiencies can be explained in terms of strengths and limitations in underlying operations. Subsequent training or remediation could be tailored to only those processes requiring treatment.

In addition to studying individual differences in the combination of operations into strategies, further research is directed toward assessing the predictive validity of single- and multiple-component predictors for criterion measures having varying degrees of complexity and specificity.

Reference Notes

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Table 1

Scanning Indices

Total Number of Fixations. The total number of times the subject shows an absence of change in eye position >1 deg. for ≥ 125msec.

Total Distractor Excursions. A distractor excursion is defined by two successive fixations, the first of which occurs within the stimulus array; the second fixation is located within the distractor field. A distractor excursion indicates a break in processing within the stimulus array to attempt conformatory activity. The total number of distractor excursions is found by summing over trials.

Percentage of Fixations Prior to First Distractor Excursion. This index is found by dividing the number of fixations occurring prior to the first distractor excursion by the total number of fixations per item.

Total row scan. A total row process is defined as the occurrence of three successive fixations on three points within a single row of the stimulus array. Examples of total row scans are: A_1-A_2-A_3 and A_2-A_3-A_1.

Total column scan. A total column scan is defined as the occurrence of three successive fixations on three distinct points within a single column of the stimulus array. Examples of total column scans are: A_2-B_2-C_2 and A_3-C_3-B_3.

Binary row scan. Three successive fixations between two points in a row.

Binary column scan. Three successive fixations between two points in a column.